ARMY GROUND FORCES
MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 2-22
724-1 GNOML

8 March 1944

1. PROJECT: No. 2 - Operations at High Temperatures. Second Partial Report on Sub-Project 2-22, Determination of the Amount of Heat Transmitted to the Fighting Compartment of Tanks Under Field Conditions.

a. Authority - Letter Commanding General, Headquarters Armored Force, Fort Knox, Kentucky, File 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose - To study recorded climatic data from representative theatres in relation to conditions of heat and humidity inside tanks, and to indicate the probable operating areas where additional cooling facilities for tank crews may be required.

2. DISCUSSION:

a. The air temperature and humidity inside closed tanks is raised above outside levels as a result of the heat added by the sun, transmission and final drive and by dissipation from crew members.

b. In the open tank the rate of ventilation is generally high enough to carry off this extra heat without serious increase in heat inside the vehicle. With the tank buttoned-up, however, and with engine idling, the ventilation rate is inadequate and marked elevation of temperature and humidity may occur. In combat areas where outside condition of heat and moisture are close to the limit of human tolerance, this increase may be sufficient to render the tank atmosphere wholly intolerable for continuous effective work.

c. The heat gain experienced in tanks operating with various rates of ventilation and with varying outside conditions has been studied and maximum limiting outside conditions determined above which the inside of the vehicles will become excessive.

d. The climatic records representing various theatres of operation have been studied in relation to these maximum desirable conditions in order to determine the need for further improvement in crew-compartment ventilation.

e. Details of the study are given in the Appendix.

3. CONCLUSIONS:

a. In certain Asiatic, Central and Southwest Pacific areas, the climatic conditions are such as to require improvement in tank ventilation and cooling of the crew if operations in closed tanks are to be sustained for more than two (2) hours.

b. Increasing the minimum rate of ventilation and improving the distribution of air flow through the crew compartment and decreasing the heat transfer from the transmission and final drive housings to the crew space will result in material improvement and may be adequate for crew members normally clothed. When anti-gas impregnated clothing is worn, however, additional cooling by refrigeration will be required.

4. RECOMMENDATIONS:

a. That field experience with respect to the heat problem in tanks operating in Pacific areas be obtained for study to determine the need for further improvement in tank ventilation and crew cooling.

b. That the study and development of individual crew cooling methods, now being conducted by Ordnance, be actively pursued.

(NOTE: The conclusions and recommendations set forth above have been concurred in by Headquarters, Armored Center, W. H. Nutter, Colonel, G.S.C., Chief of Staff.)

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Appendix with Table 1 and 2,
Figures 1 thru 8

# APPENDIX

1. It is generally hotter and less comfortable inside than outside closed armored vehicles operating in hot climates. In those areas where the ambient condition is near the limit of human tolerance, the extra heat burden to which tank crew members are exposed may be sufficient to render the inside atmosphere quite intolerable for continuous operation and thus limit seriously the usefulness of the vehicle in combat. There is evidence that such a limiting condition may be developed in existing armored vehicles from the recent experience in tank warfare in New Guinea and other Southwest Pacific areas where the tanks have to be operated buttoned-up. Since the climate involved is no worse than in other areas in the Pacific theatre, it becomes desirable to consider carefully the probable heat problem and, where necessary, to offset it by the required means.

2. Sources and Magnitude of Added Heat Load in Tanks. The excess heat burden inside tanks as compared with outside arises from three principal sources: heat of transmission and final drive, solar heat absorbed through walls and heat given off by crew members. The heat from these sources is removed by the air flowing through the crew compartment and the degree to which the inside atmosphere is heated varies inversely with the rate of ventilation. In the M4 tank, with its system of negative ventilation, the rate of airflow varies widely with engine speed. In the buttoned-up M4A3 vehicle, for example, the minimum rate is 300 cfm, with the engine idling, and increases to approximately 1500cfm at normal cruising speed.

3. The magnitude of the heat gain in the standard M4A3 tank operating at normal cruising speed with hatches closed (ventilation rate approximately 1500 cfm) and in an experimental positive-pressure tank provided with ventilation at a rate of 200 cfm, are compared in Table 1. These data represent conditions after five hours of operation at Fort Knox during July (the last 1½ hours driving was done buttoned-up). The relatively greater increase in temperature and particularly in humidity in the positive-pressure tank is striking. The effective temperature inside the tank exceeded the tolerable limit for continuous effective work on days when the outside temperature was approximately 90°F and the relative humidity 50%. This may be contrasted with the much higher rate of ventilation through the standard vehicle, the inside conditions remained within tolerable limits although significantly elevated above outside conditions. The importance of sufficient ventilation is thus demonstrated. In this connection it may be recalled that the rate of ventilation in the standard tank when the engine is idling is only 300 cfm; in such a situation, therefore, inside atmospheric conditions would approach those reported for the experimental positive-pressure tank. Reports from the South Pacific theatre indicate that in combat, tanks remain stationary, buttoned-up and with the engine idling for considerable periods of time, which would account for the troublesome heat problem which has been reported. The observed results given in Table 1 for the standard tank and the pressure tank under similar outside conditions are plotted on the psychrometric chart, with effective lines superimposed, in Figure 1.



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TABLE 1

ATMOSPHERIC CONDITIONS IN CREW COMPARTMENT AT END OF 1½ HRS. BUTTONED-UP DRIVING COMPARED WITH OUTSIDE CONDITIONS

| TANK | OUTSIDE COND. | | | | INSIDE COND. | | | | HEAT GAIN | | | RATIO SEN. TO TOTAL HEAT GT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $t_d$ | $t_w$ | ET | Total Heat | $t_d$ | $t_w$ | ET | Total Heat | Total | Sen. | Lat. | |
| Standard M4A3 | 90 | 76 | 82 | 38.7 | 100 | 83 | 88 | 45.7 | 7.0 | 1.9 | 5.1 | 0.27 |
| Experimental M4A3 | 91 | 75 | 82 | 37.7 | 106 | 94 | 96.5 | 59.6 | 21.9 | 3.5 | 18.4 | 0.16 |
| Experimental M4A3 | 86 | 76 | 80 | 38.7 | 105 | 93 | 94.5 | 58.0 | 19.3 | 4.8 | 14.5 | 0.25 |
| Experimental M4A3 | 75 | 68 | 72 | 32.0 | 97 | 86 | 89.0 | 49.0 | 17.0 | 5.2 | 11.8 | 0.31 |

In the standard tank with a ventilating rate of 1500 cfm, the calculated total heat gain within the vehicle amounted to 47000 Btu/hr. In the experimental tank, on the other hand, with 200 cfm ventilation rate, the calculated total heat gain was only 18000 Btu/hr. The great difference between the two calculated values of total heat gain is explained, in part, by the incomplete mixing of air within the vehicles. Because of this, the heat gain at the several crew positions in the standard tank was excessively increased as compared with the gain for the vehicle as a whole.

4. Magnitude of heat gain in relation to acceptable operating condition. An effective temperature of 90° is commonly taken to represent the upper limit of combinations of temperature and humidity which can be tolerated with continuous effective work. Accepting this as the maximum desirable limit in a closed tank, it becomes possible, from the data for the experimental tank in Table 1, to estimate the upper limit of outside conditions which should not be exceeded for efficient use of the vehicle. Assuming the same total heat gain and ratio of sensible to total heat gain as was observed in the experimental tank, the limiting outside conditions may be determined for a maximum inside condition anywhere along the 90° ET line. The resulting limit is shown in Figure 1. Since the amount of heat gain decreases with increasing ventilation rate, it is also possible to calculate the lines of limiting outside conditions for other ventilation rates, assuming the same ratio of sensible to total heat gain. This has been done for 300, 400 and 600 cfm and the corresponding lines are shown in Figure 1. The value of increasing ventilation is evident from the relative position of these lines. The standard vehicle with engine idling has a ventilation rate of about 300 cfm. Recent work on canister design by CWS indicates that a rate of ventilation of 400 cfm



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may be obtained through a gas canister of acceptable size for use in a gas protected tank. A consideration of the outside limits for these two ventilation rates indicates that the outside effective temperature must not exceed 80° in order to insure an effective temperature inside the tank not greater than 90°. In the analysis of climatic conditions in the various theatres, which follows, a limiting outside condition of 80° ET has been selected as the maximum tolerable limit.

5. Climatic Conditions in geographic areas in relation to selected limit. Climatic conditions in areas representative of combat theatres in the Pacific and in Southern Europe have been studied in relation to the selected tolerable limit of 80° E.T., with the results shown in Figures 2 to 7. Tables of meteorological data from the Hydrographic Office, and Weather Research Center, AAF, were consulted. Records were available for the following: mean, minimum and maximum daily temperature, extreme maximum and minimum temperatures, and mean daily relative humidity, all by months. Owing to the incompleteness of meteorological data available for study it was necessary to make certain assumptions and adopt certain procedures in the construction of the curves, as follows:

a. The mean vapor content, obtained from the reported mean daily temperature and relative humidity, was assumed to remain constant for all variations in temperature during the month. This is undoubtedly somewhat incorrect since during periods of abnormally hot weather there would be a corresponding increase in moisture content of the air. The error in estimation of effective temperature is, however, on the low side so that actual conditions are rather worse than here predicted.

b. Using the mean vapor content for a given month the effective temperature corresponding to the daily mean minimum and maximum temperatures for the month and to the extreme minimum and maximum temperatures were obtained from the ASHVE effective temperature chart (still air). The effective temperatures thus obtained are plotted together with the daily mean and maximum and extreme maximum temperatures and the mean vapor content of the air throughout the year in Figures 2a to 7a.

c. The curves of diurnal variation, shown in Figures 2b to 7b for the hottest month at each station, were constructed in the following manner:

(1) The mean daily maximum and minimum temperatures were plotted as 50% values on logarithmic probability paper and the extreme maximum and minimum levels as the 99.9% and 0.1% values*, respectively. Straight lines were drawn through the 50% and 99.9% maxima and the 50% and 0.1% minima, as shown in Figure 8. The extrapolation of these lines to the left and right permitted the prediction of the minimum temperature on the day of extreme maximum record and *vice versa*. The diurnal variation of the predicted 25%, 90%, etc. days were also determined from these lines.

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* The values 99.9% and 0.1% were employed since the records were generally for about 30 years, thus giving approximately 1000 observations.



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(2) The minimum and maximum daily temperatures were assumed to occur at 0500 and 1500 hours at all stations and at all seasons. There is little justification for this assumption except that the error introduced is on the low side during the hot season or because of closeness to the equator, there is little seasonal change. The diurnal temperature curves were drawn free-hand through the plotted points.

(3) Assuming the vapor content to remain constant at the mean level for the month in question, the diurnal effective temperature curves corresponding to the curves of diurnal temperatures for the mean and extreme days of record and the 90% day, 25% day, etc., as desired, wer constructed.

6. The stations employed in the present study were selected to represent climatic conditions in broad theatres: Penang, being a coastal city close to the equator, represents the entire coastal and insular areas in the equatorial Pacific zone as indicated by the close similarity of temperature records for stations throughout this zone. Such areas as the Southern Philippines, Malay, coastal regions of Dutch East Indies, New Guinea and the many smaller islands are represented by the Penang station. Mandalay represents the jungle country in the interior of Burma and Indo-China. Hong Kong was included to show the improved conditions in coastal regions somewhat north of the equator. Records for the interior of China and the Japanese Islands were found to be significantly better than for Hong Kong. The data for New Orleans have been included for comparison. Marseilles and Fiume are representative of the Scurthern Coast of Europe and yield records of hotter weather than is found in the interior of that continent or on its west coast.

7. Results of study of these curves are summarized in Table 2, which gives, for the mean year and for the hottest year out of ten the number of months when the effective temperature exceeds 80° during the day:

a. For any length of time.

b. At least six hours a day.

c. At least twelve hours a day.

For purposes of comparison, the data for the six stations are separated into three zones. In the first zone (Sourthern Europe) the limiting effective temperature of 80° will be encountered only rarely; in the second (coastal and insular regions and interior jungle areas, up to 30°, north of the equator) the limit will be exceeded during four to nine months each year; in the third zone (equatorial Pacific coastal and insular areas) the climatic conditions will be above the selected limit for practically the entire year. In the light of these results, the following conclusions are drawn:

(1) Atmospheric conditions in European theatre are such as not to require changes in tank ventilation or the use of additional cooling facilities to insure effective operation of the closed vehicles in combat.



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(2) Atmospheric conditions throughout the year in the insular and coastal regions and interior jungle regions of the equatorial Pacific Theatre are such as to require the application of additional facilities for crew cooling in tanks which are to operate effectively for several hours with hatches closed. This applies to present standard tanks in engagements which are characterized by slow advance with the tank stationary (engine idling) a high portion of the time and especially to tanks in which the crew must be protected against chemical attacks by whatever means, since in all instances the crew are required to wear impregnated clothing.

(3) In the coastal and interior regions of Southern China the atmospheric conditions are such as to require improvement in crew compartment conditions for from 4 - 6 months if tanks are to operate in prolonged engagements with hatches closed. For combat under prolonged gas attacks, particularly, such correction will be required.

8. Means for improving crew compartment conditions.

a. Deterioration of the crew compartment atmosphere from the standpoint of heat burden in comparison with outside conditions results from the insufficient capacity of the crew compartment ventilation to remove the added heat. The situation in the present standard tanks is critical in this respect when combat conditions are such that the closed vehicle remains stationary for prolonged periods with the engine idling. The most direct means for increasing the rate of crew compartment ventilation at minimum engine speed would be to provide a larger opening in the bulkhead and means for increased air flow through hull and turret openings - such as an auxiliary fan in the bow. A minimum ventilation rate of 1000 cfm, well distributed through the crew compartment, is suggested. For further improvement, it is recommended that the transmission and final drive housings be insulated. It must be emphasized that these corrections are adequate only under combat conditions where chemical attack does not occur.

b. For tank operation under chemical attack, gas protection will be secured by means of gas masks, positive air supply masks or positive pressure ventilation of the tank through a central gas canister. With all of these methods the crew may be required to wear anti-gas clothing which markedly increases the heat stress*. For such situations it is not expected that satisfactory operating conditions will be obtained merely by increasing the rate of crew compartment ventilation and consideration should be given to the possible application of additional cooling means. In this connection some promising work has been done by Ordnance** and in Australia*** on systems

* See Armored Medical Research Laboratory Rroject No. 2 - Operations at High Temperatures, Partial Report on Sub-Project No. 2-3, Test of the Adequacy and Ranges of Use of Clothing for Jungle Operations and 2-18, Effects of Impregnated and Impervious clothing Upon the Efficiency of Personnel, 24 Nov 43.
** See Armored Medical Research Laboratory Final Report on Sub-Project No. 2-28 Test of Individual Crew Conditioning System for description of experimental model of Ordnance Suit.
*** Report No. A.F.V. 33 Tank Personnel Cooling, AFV Comm., National Health and Medical Research Council, Australia, 23 Aug 43.

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for individual crew cooling by means of a refrigerating system and facilities for direct distribution of cooled air to each member. Even in its simplest form, such a system is complicated in construction and difficult to install. Its use cannot be recommended unless operating conditions clearly require it, and a decision in this respect must be based upon actual field experience rather than on an analysis of climatic records such as is attempted here. On the other hand, considerable development work is necessary before the essential design of such a system can be established. It appears wise, therefore, to pursue this development work rapidly so that when a decision is reached as to the need, the means for correction will be ready for manufacture. The necessity for an early decision on the need for such equipment must also be emphasized because of the inevitable delay in production and delivery of the equipment in the combat area after manufacture has started.



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TABLE 2

NUMBER OF MONTHS IN MEAN YEAR AND HOTTEST YEAR IN 10 YEARS DURING WHICH EFFECTIVE TEMPERATURE EXCEEDS 80°

| Theatre Zone and Station | NUMBER MONTHS EFFECTIVE TEMPERATURE EXCEEDS 80° | | | | | |
|---|---|---|---|---|---|---|
| | MEAN YEAR | | | ONCE IN 10 YEARS | | |
| | Any day | 6 hrs/day | 12 hrs/day | Any day | 6 hrs/day | 12 hrs day |
| European | | | | | | |
| Marseilles | 0 | 0 | 0 | 0 | 0 | 0 |
| Fiume | 0 | 0 | 0 | 2 | 0 | 0 |
| Southeastern Asia | | | | | | |
| Mandalay | 10 | 9 | 7 | 12 | 10 | 10 |
| Hong Kong | 4 | 3 | 0 | 5 | 4 | 2 |
| New Orleans (for comparison) | 4 | 3 | 0 | 5 | 4 | 3 |
| Central & South Pacific | | | | | | |
| Penang | 12 | 10 | 0 | 12 | 12 | 10 |

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FIG. I

# ANALYSIS OF HEAT GAIN IN TANK IN RELATION TO RATE OF VENTILATION AND LIMITING OUTSIDE CONDITIONS FOR MAXIMUM INSIDE EFFECTIVE TEMPERATURE = 90° AT STATED VENTILATION RATES

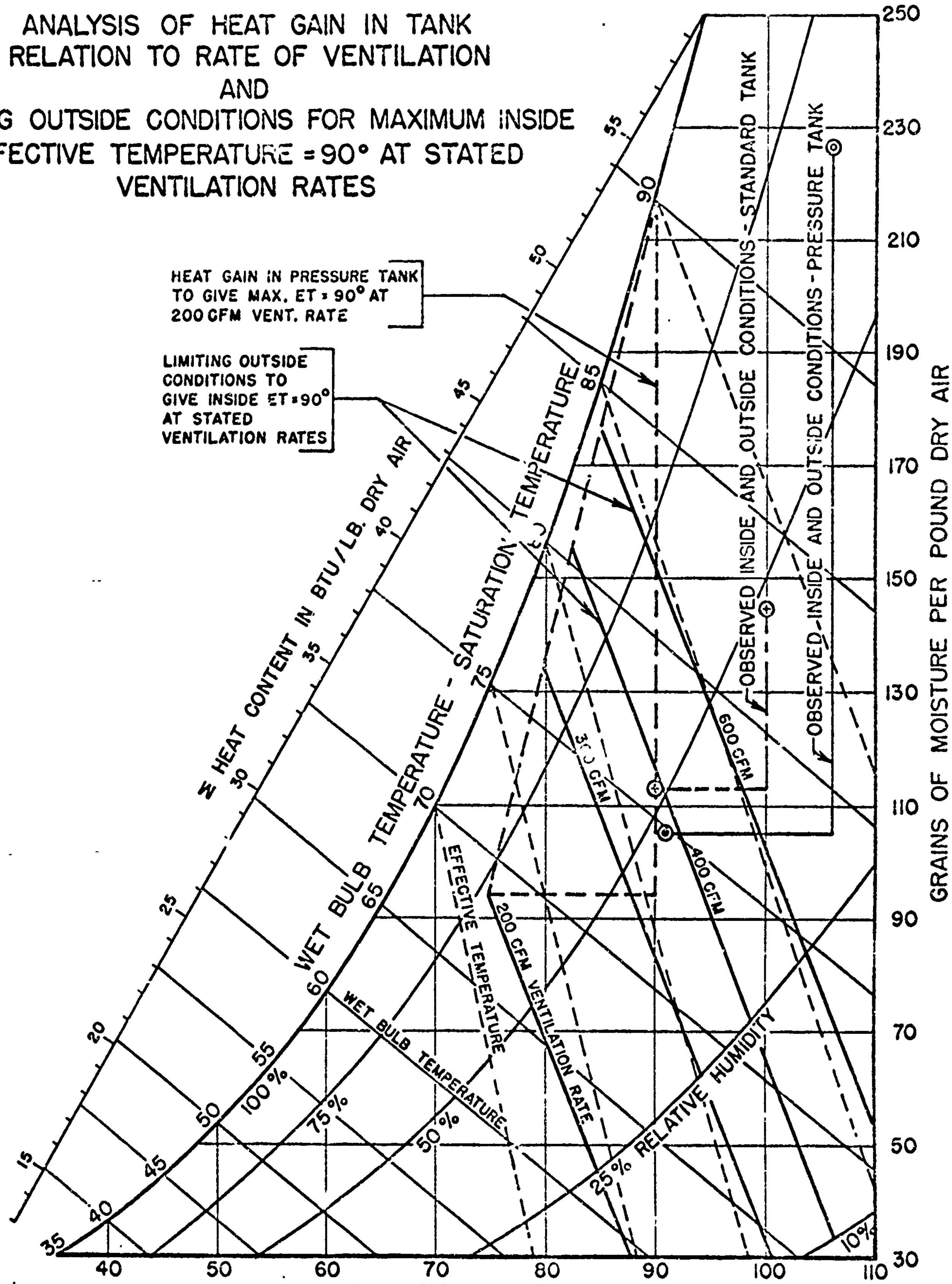


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FIG. I ARMORED MEDICAL RESEARCH LAB.

FIG. 2A

YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

MARSEILLES

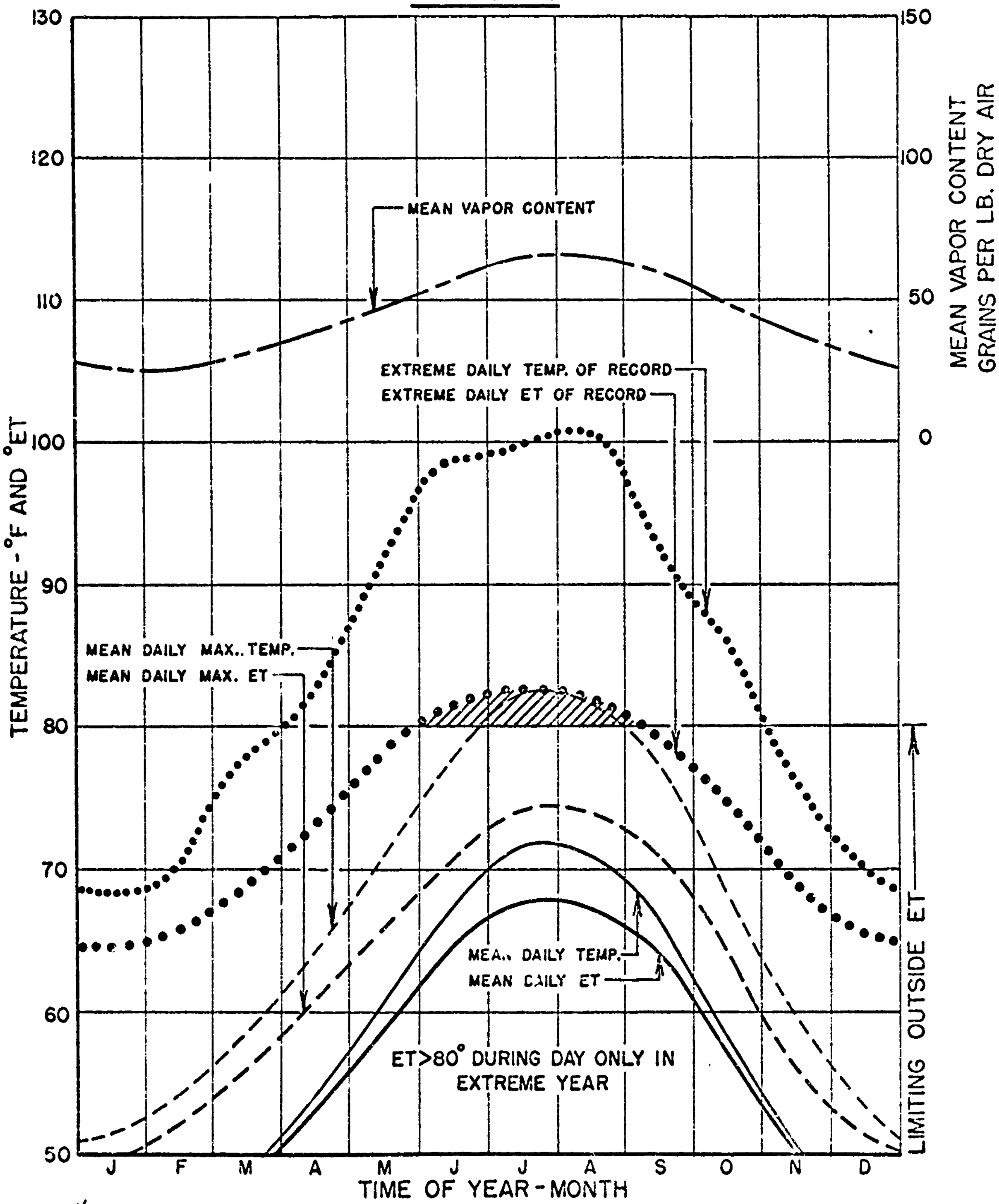


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FIG. 2A ARMORED MEDICAL RESEARCH LAB.

FIG. 2 B

DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH: AUGUST

MARSEILLES

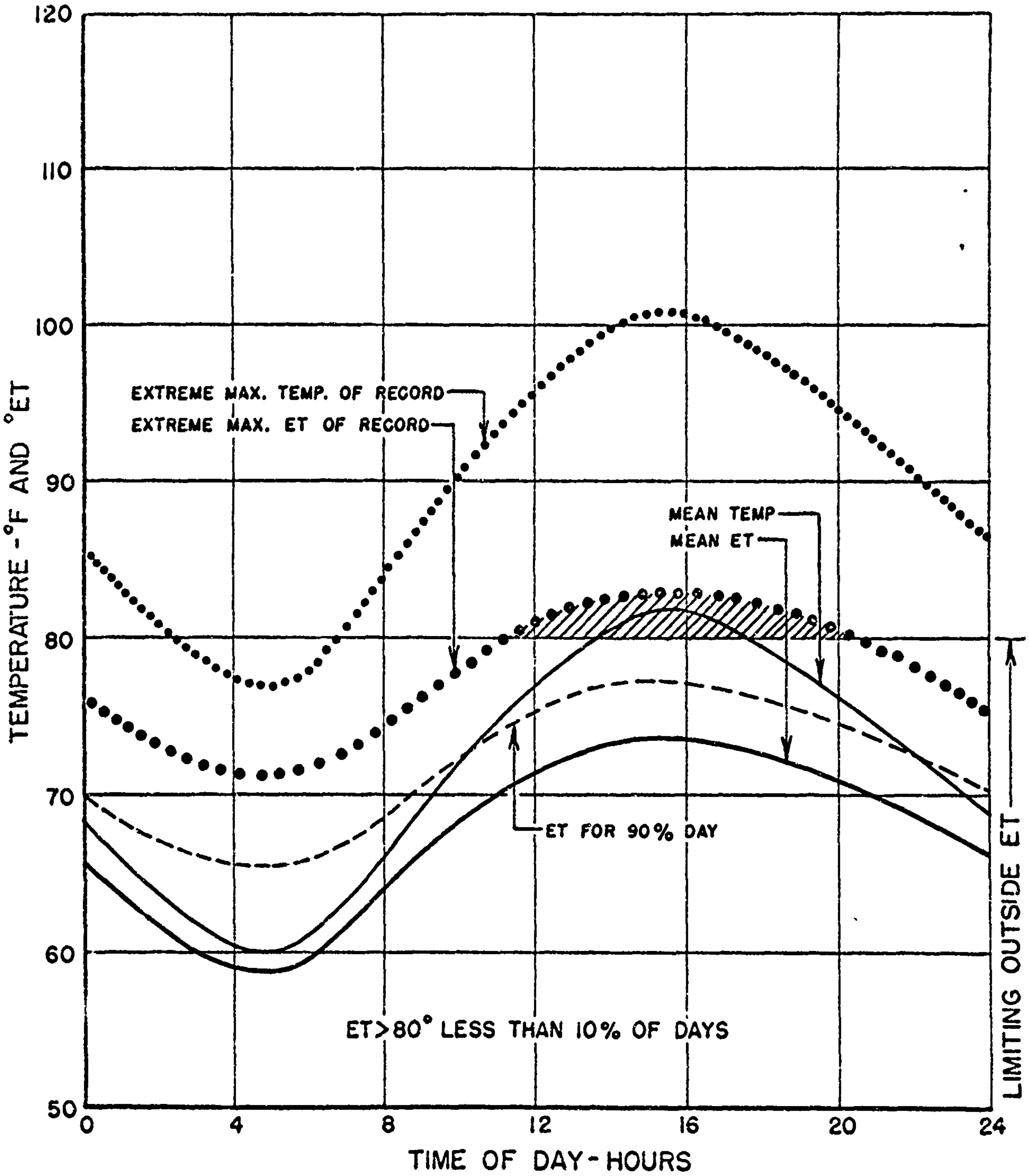


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FIG. 2 B ARMORED MEDICAL RESEAR[illegible]

FIG. 3A

YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

FIUME

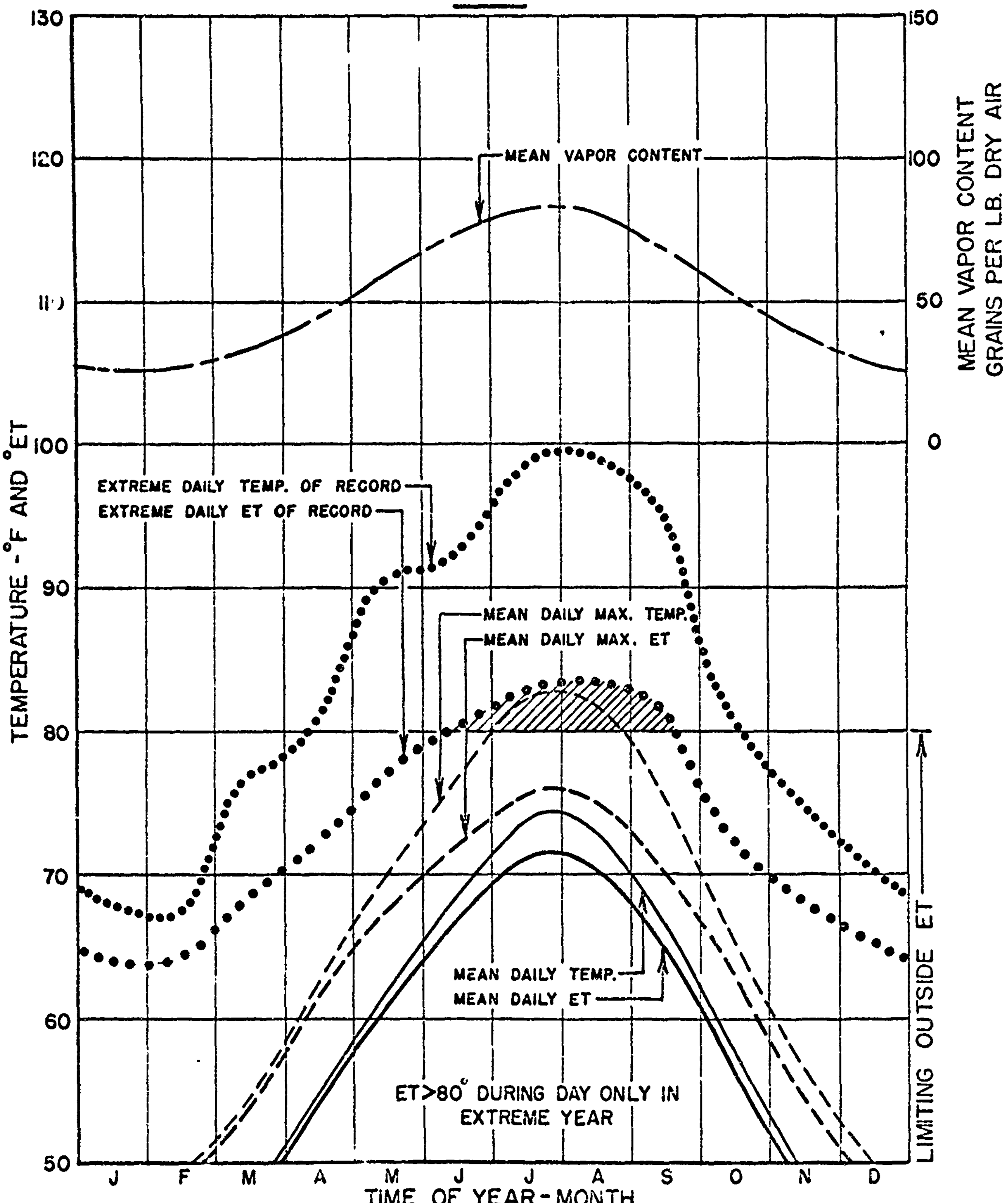


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FIG. 3A ARMORED MEDICAL RESEARCH LAB.

FIG. 3B

# DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH: JULY

FIUME

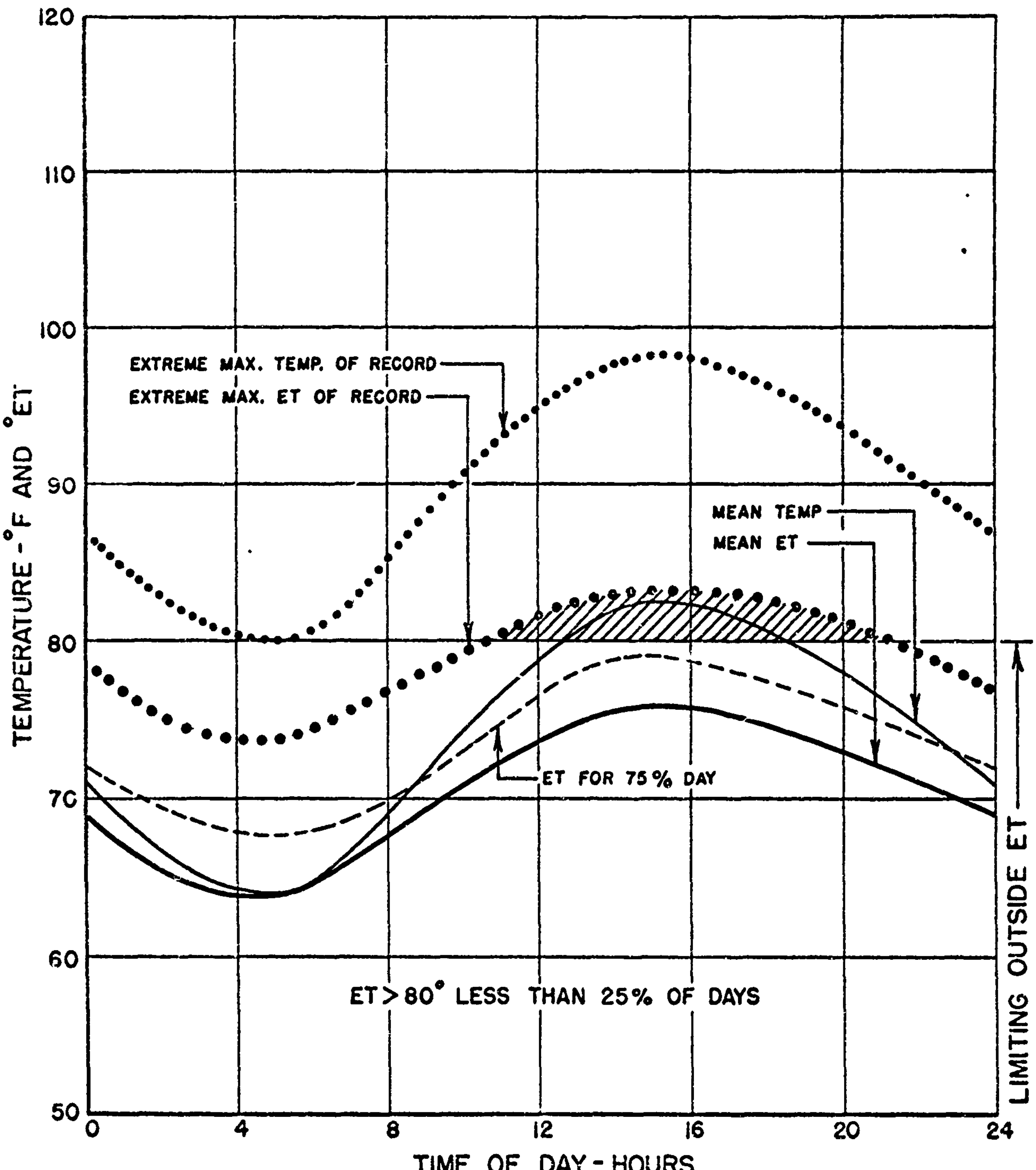


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FIG. 3B ARMORED MEDICAL RESEARCH LAB.

FIG. 4A

# YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

## HONG KONG

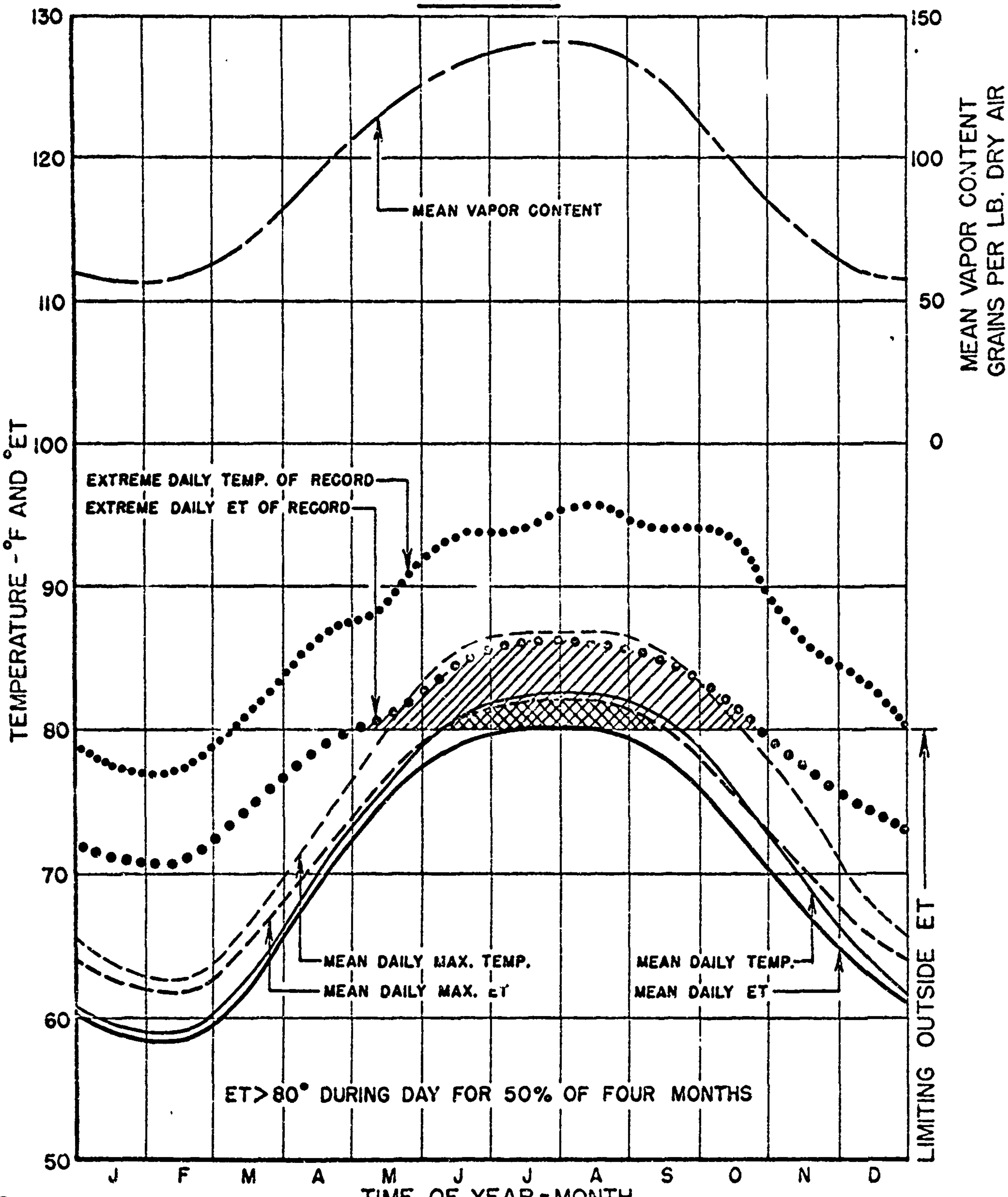


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FIG. 4A ARMORED MEDICAL RESEARCH LAB.

FIG. 4 B

DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH: AUGUST

HONG KONG

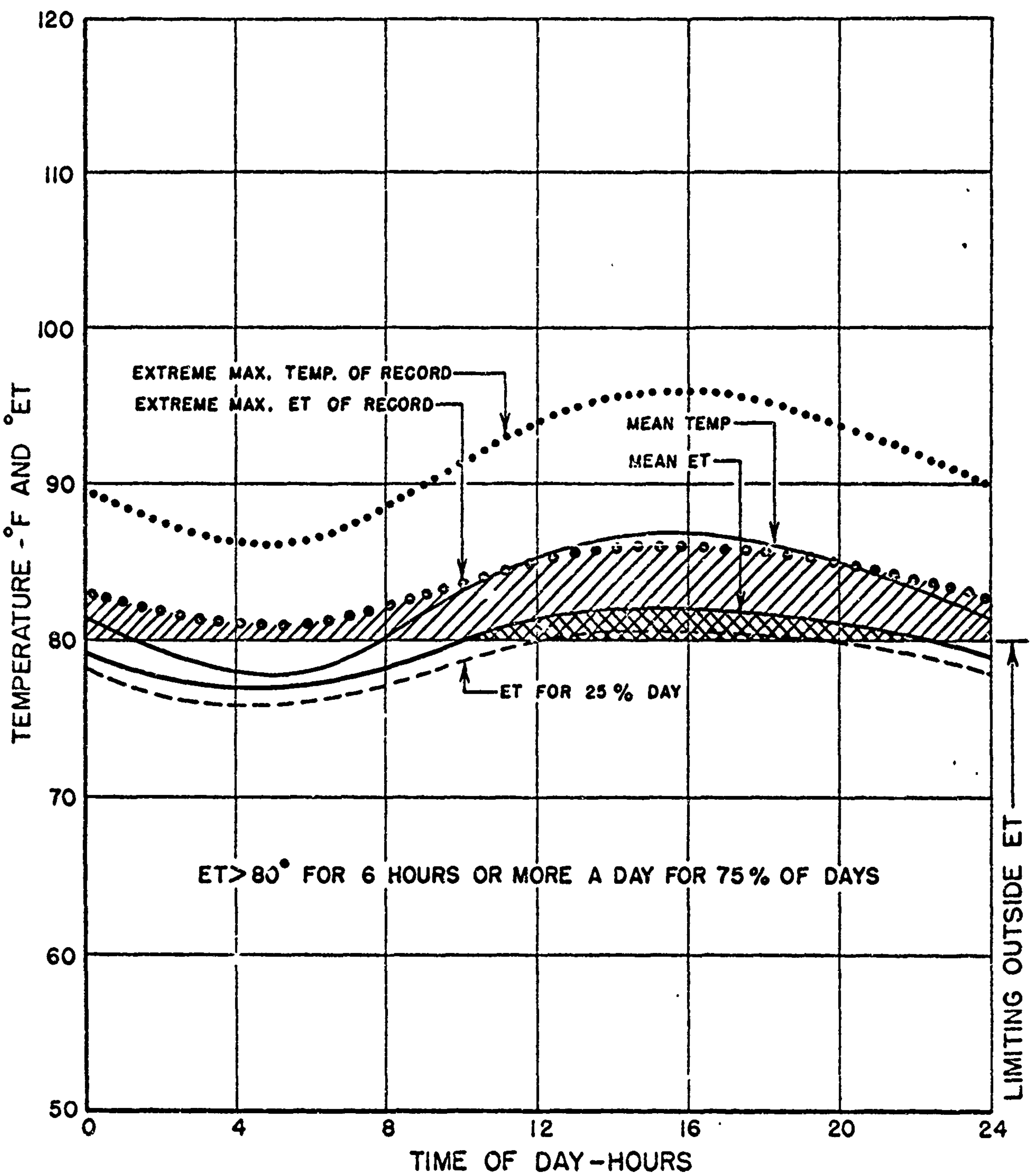


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FIG. 4 B ARMORED MEDICAL RESEARCH LAB.

FIG. 5 A

YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

NEW ORLEANS

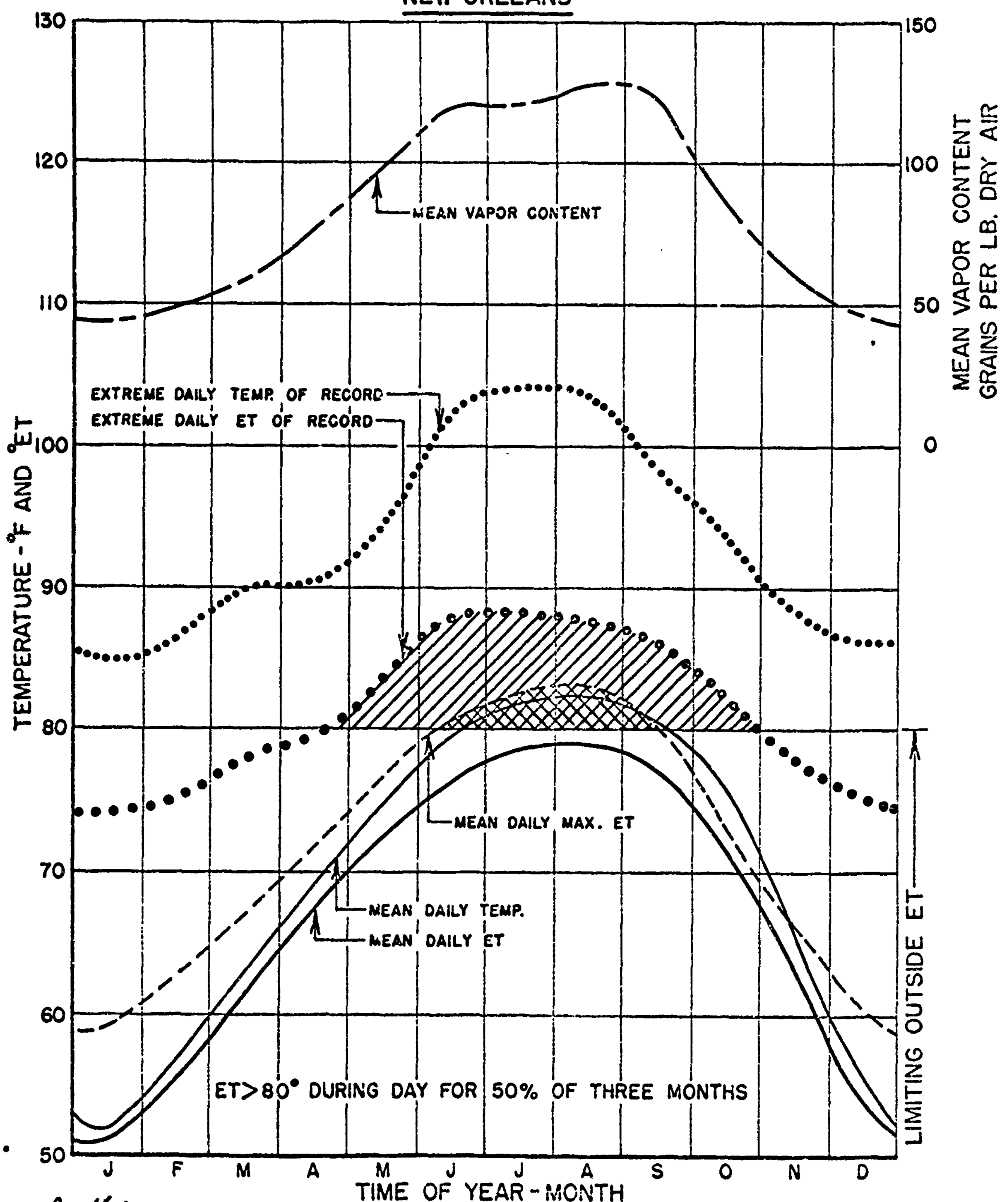


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FIG. 5 A ARMORED MEDICAL RESEA[illegible]

FIG. 5B

DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH: AUGUST

NEW ORLEANS

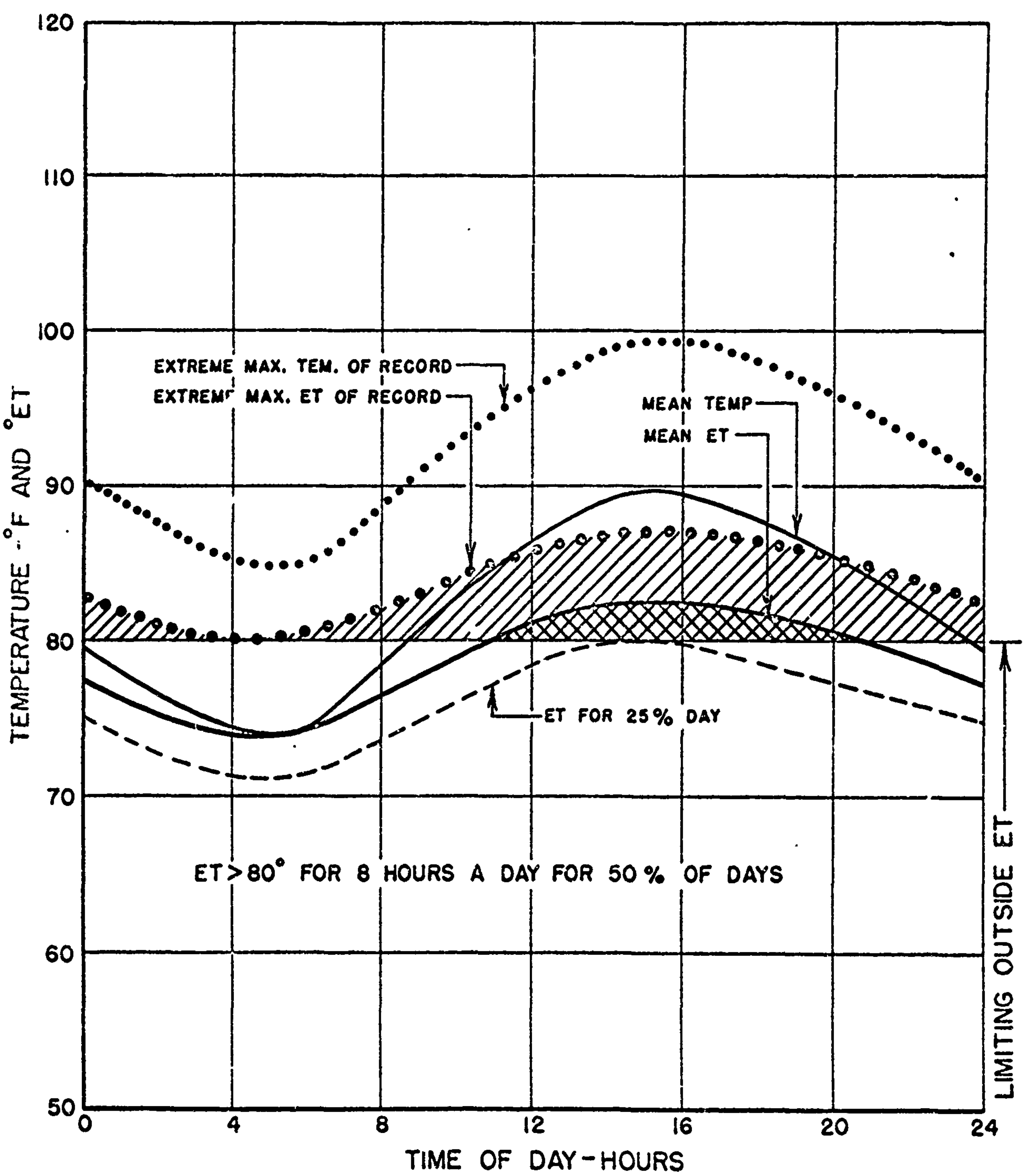


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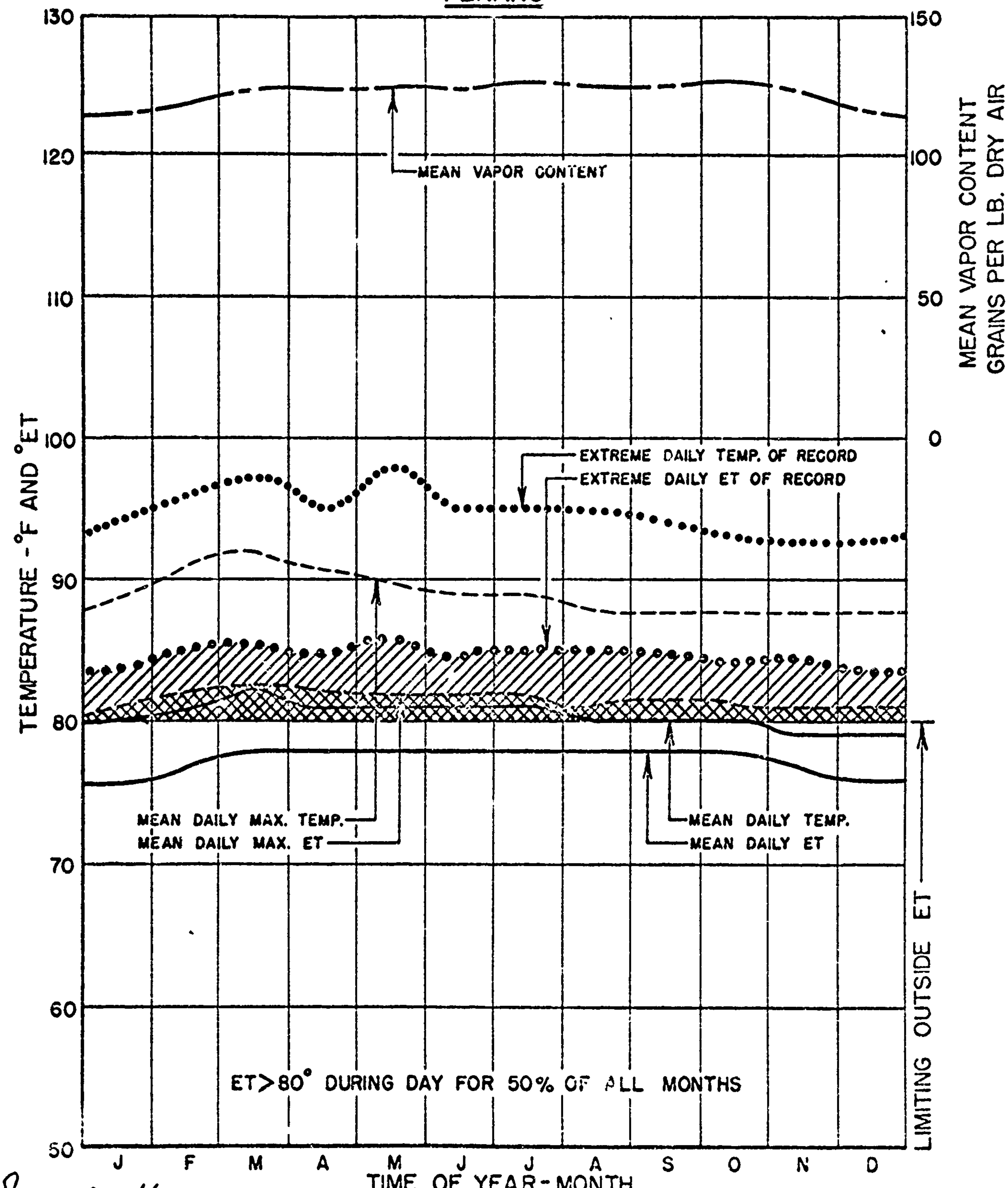
FIG. 5 B ARMORED MEDICAL RESEARCH LAB.

FIG. 6A

YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

PENANG

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# DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH : MARCH
PENANG

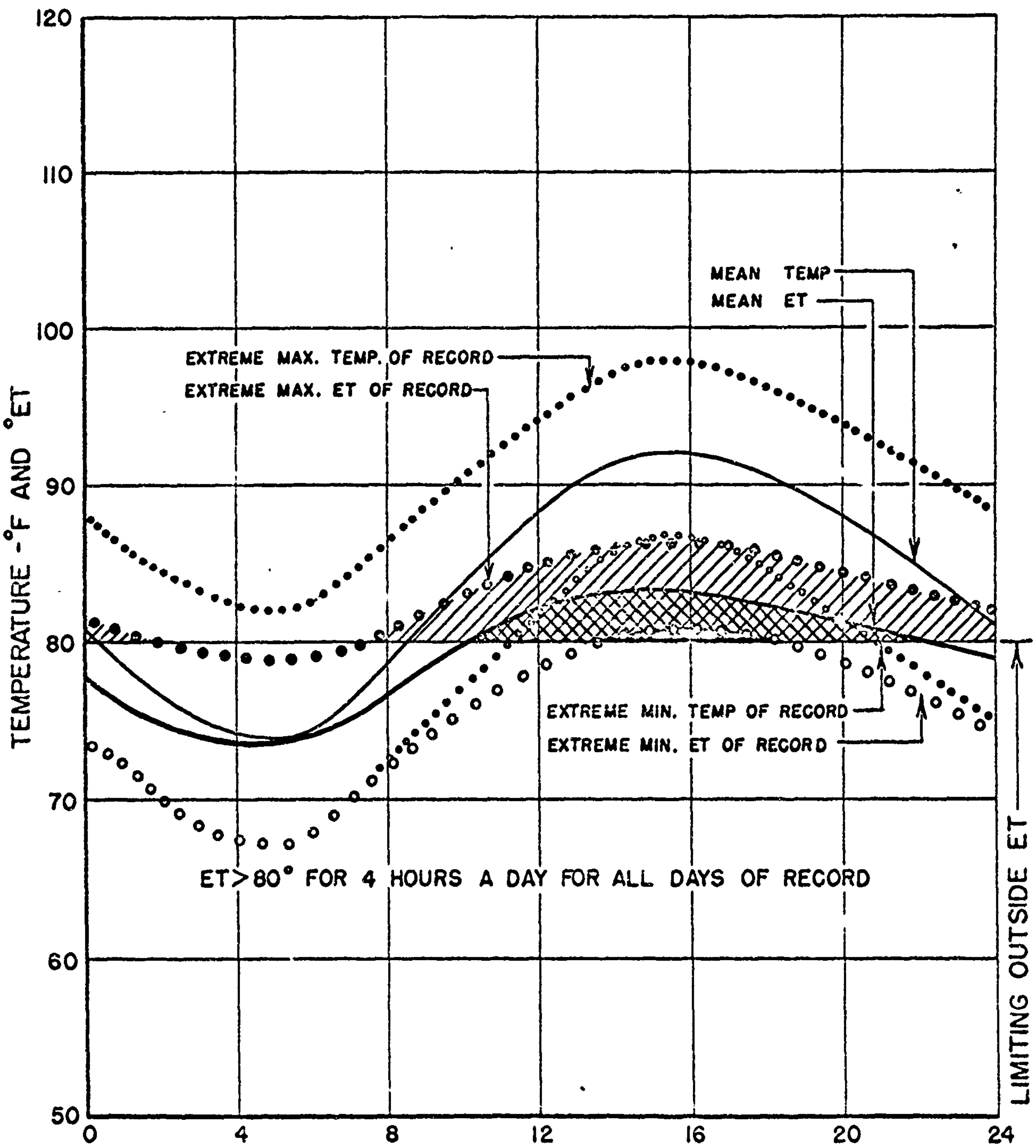


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FIG. 6 B

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FIG. 7A

YEARLY VARIATION IN TEMPERATURE, VAPOR CONTENT AND EFFECTIVE TEMPERATURE

MANDALAY

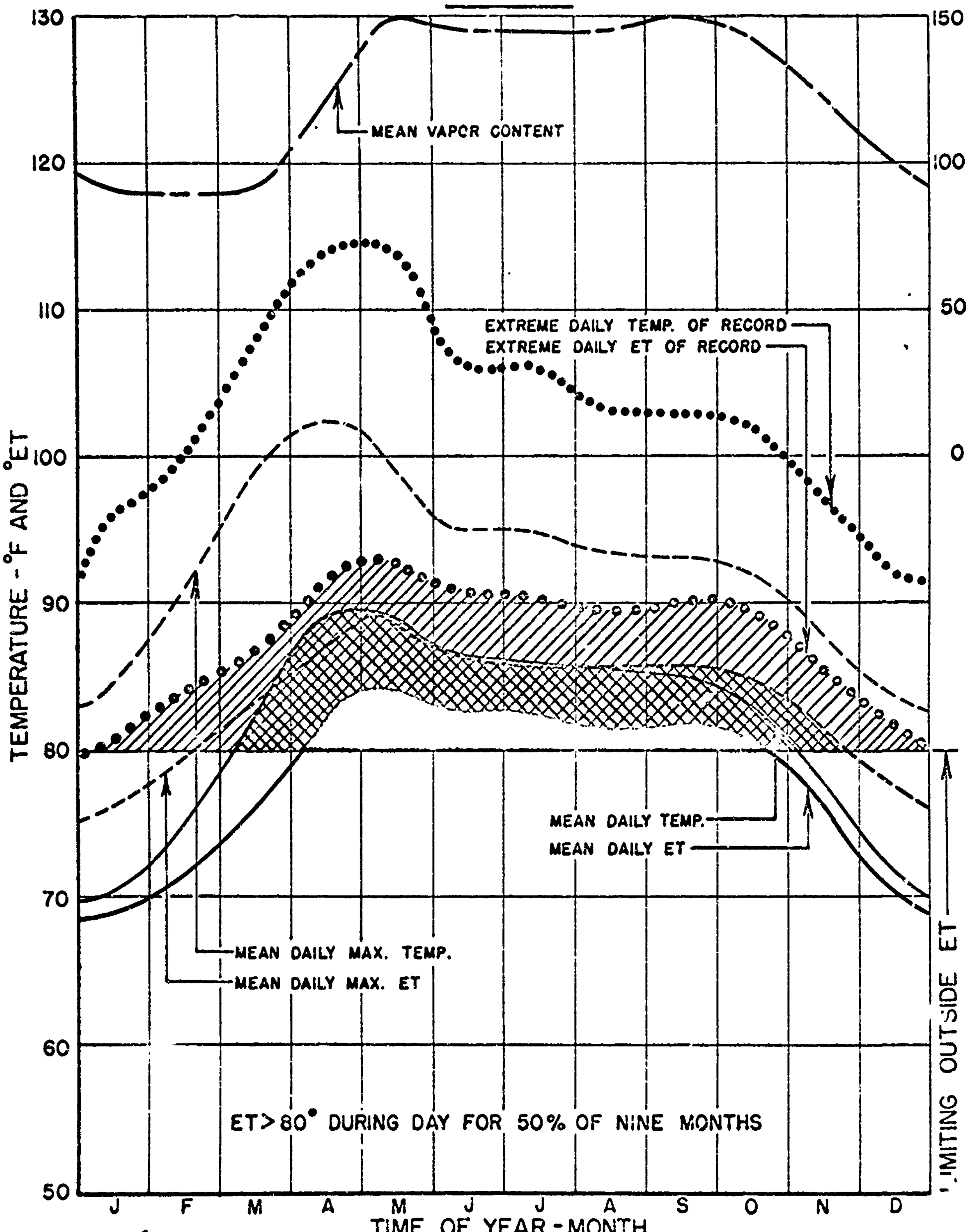


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FIG. 7A ARMORED MEDICAL RESEARCH LAB.

FIG. 7 B

DIURNAL VARIATION IN TEMPERATURE AND EFFECTIVE TEMPERATURE

HOTTEST MONTH: MAY

MANDALAY

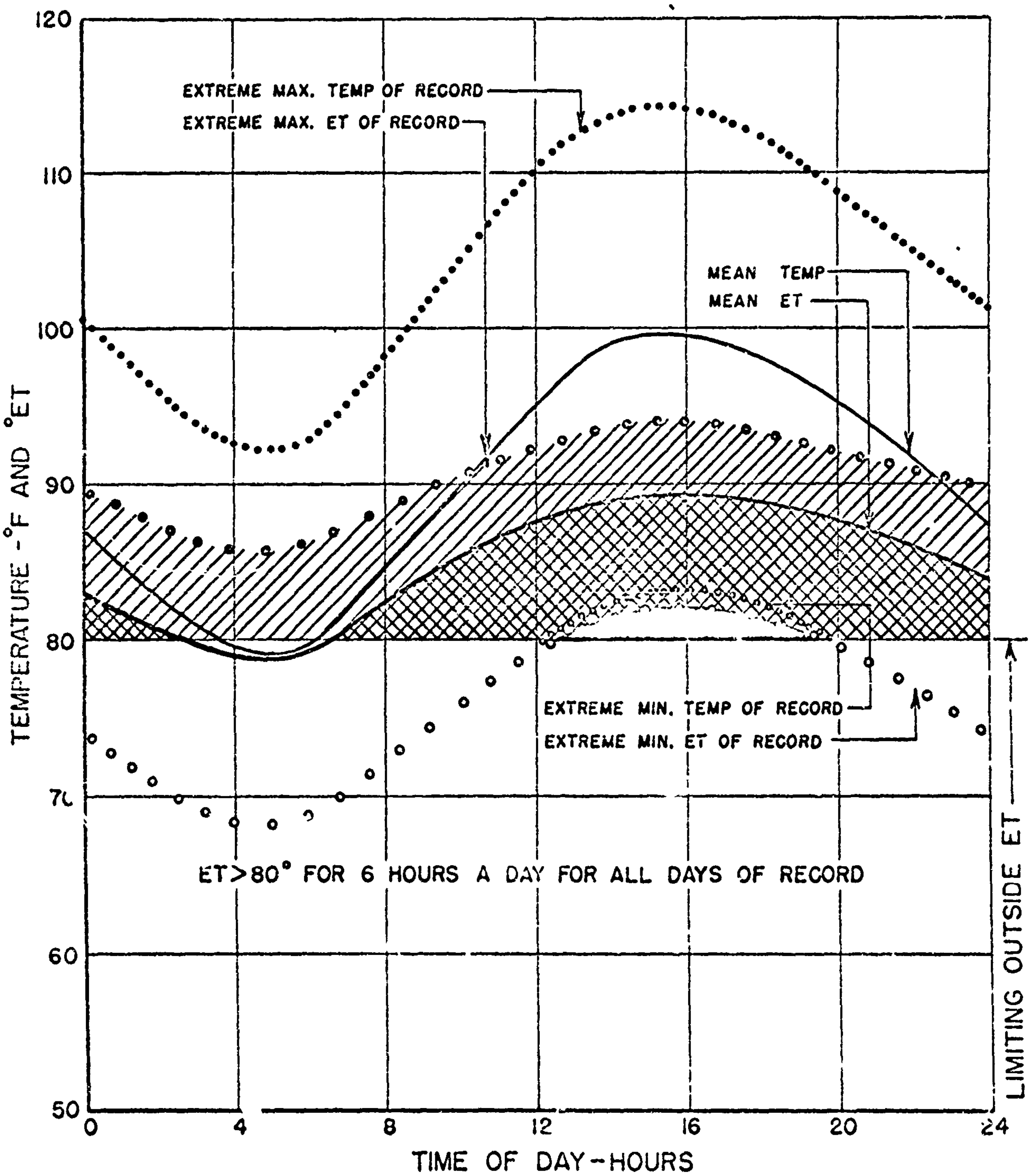


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FIG. 7 B ARMORED MEDICAL

FIG. 8

ESTIMATION OF DIURNAL TEMPERATURE RANGE
FOR DAYS INTERMEDIATE BETWEEN MEAN AND EXTREMES OF RECORD

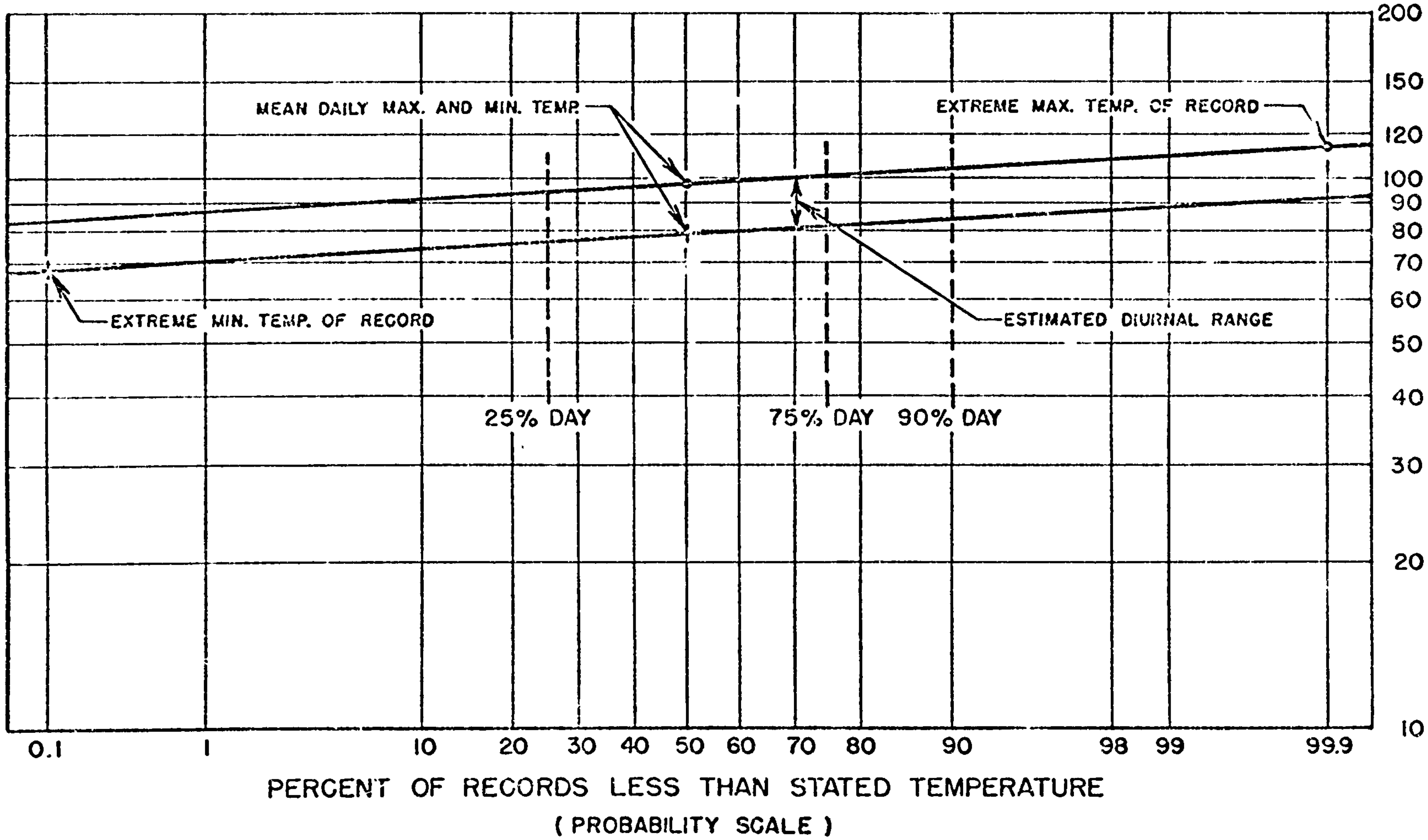


FIG. 8

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